CATV COAXIAL CABLES STANDARDIZATION??

by

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The fundamental problem of engineering is the effective production and utilization of the materials and forces of nature. Our complex civilization is dependent upon our increased ability to transport material and energy from the point where it is available to the place where it can be utilized.

The electrical engineer is interested in the production and utilization of the forces of nature, most of which are, both initially and finally, in some form other than electrical. He uses the electrical link because it is one of the most efficient and rapid means available for the transportation of energy. The power engineer may first transform the latent chemical energy of coal or oil into thermal or mechanical energy. After using this mechanical energy to produce electrical energy, he transmits it to some distant point where it again may be transformed into mechanical power by a motor or into radiant energy thru an electric lamp. Similarly, the communication engineer receives acoustical energy for his telephone, mechanical energy for his telegraph, or radiant energy for his television. These forms of energy must be delivered to the receiving end in almost identical form as originated.

The problem of the electrical engineer, therefore, is to pass on energy from one part of a system to another until it is ready for utilization. This usually means passing through a number of devices, each one of which may take its toll by subtracting from or modifying the energy handled.

As the middleman, if not controlled, may alter the amount or quality of produce passing from the farmer to the consumer, so the electrical transporting units containing resistance, capacitance, inductance, etc., may unduly reduce the amount or alter the character of the electrical impulses they receive for delivery to a distant point.

In the CATV industry, insulated electrical cables play a very important role. However, their construction, characteristics and usefulness are not generally immediately perceptible in contrast to the more glamorous components such as amplifiers, modulators, spectrum analyzers, etc., and the inconspicuousness of their contribution to the industry is often the very cause of their being overlooked. Without cable, however, many accomplishments of our industry would not be possible.

It is to the everlasting credit of our industry's pioneers that they were able to adapt or convert available commercial and military cables to perform the miracle of CATV. These great "Imagineers", many of whom are in attendance at this convention, needed, above all, the ability to improvise and innovate. They did not need industry standards and, as a matter of fact, had standards been available, they may well have stifled imagination and inhibited growth of this great industry.

Whether or not the state of the CATV art has advanced to the stage where broad standards covering the many various components are now possible, is beyond the scope of this paper. However, it is the opinion of this writer, that the industry has matured to the point where standards to cover CATV cables are both possible and necessary.

The CATV industry has, like Topsy -- 'just growed'. In its first seven years of existence or by year end 1957, the industry had grown to about 580 operating systems. The average miles per system for these years has been estimated at about 38 miles. During 1966, 258 new CATV systems were built with an estimated 50.5 miles per system. As shown in Table A, the cable footage to be used by the CATV industry is expected to double in volume during the next 5 years to an overall figure in 1971 of 266,000,000 feet.

TABLE A

Year End	Avg. Miles/System	Est. Cable Footage	New Systems	Net Operating Systems
1967	59	131,000,000	350	2300
1968	62	184,000,000	470	2770
1969	64	215,000,000	530	3300
1970	66	242,000,000	580	3880
1971	68	266,000,000	620	4500

We feel that figures such as these make it all the more evident that there is an immediate need for the establishment of meaningful yardsticks by which the mechanical and electrical properties of this highly important system component can be evaluated.

The validity of this premise is a matter for the CATV industry, to whom the cable manufacture plays a supporting role, to decide. This paper, therefore, is not intended to promulgate specific standards but rather to invite the industry's attention to the fact that wide variations in cable constructions for CATV use, do exist. This discussion will also review areas of design, production and testing of aluminum sheathed CATV cables to support our position that meaningful parameters by which the mechanical and electrical properties of cables are evaluated, can now be established.

In an overall CATV system, the final umbilical link between an accumulation of many exotic and expensive pieces of equipment and your customer's TV set is a $2.50 piece of coaxial cable generally referred to in the industry as RG-59/U.

In the initial days of CATV, I am sure that the military RG-59/U coaxial cable was selected because it met the basic requirements of the system, and it was available. Over the years, in order to lower the cost of cables, there have been several changes in construction and, likewise, performance characteristics, without any change in terminology. Such use of deceptive terminology is a gross misapplication of intent.

The terminology for coaxial cables "RG-( )/U" was devised by the military initially in 1944 under their joint Army-Navy Specification JAN-C-17. Basically, their coaxial terminology is derived at as follows:

"R" - Means Radio Frequency
"G" - Means Government
"(59)" - The number assigned to the Government approval.
"/U" - Means it is a universal military specification.

If the letters A, B, C, etc. appear before "/", it means a specification modification has been made. Only cables made to the Government specification and meeting the requirements of that specification should be marked with the "RG" legend.

In Table B, we have outlined the basic constructional details for coaxial cable RG-59/U as initially specified under JAN-C-17.

With the change from the "JAN" classification to the "MIL" classification, changes were made in the constructional and electrical requirements for this coaxial cable. The requirements for RG-59B/U coaxial cable are outlined in Table C.

The distinguishing differences between the requirements for RG-59/U and RG-59B/U cables are:

(1) Conductor size changed from 0.0253" to 0.0230".
(2) Conductor conductivity requirements changed from 30% to 40%.
(3) Recognition in the latest issue of high molecular weight polyethylene insulating material.
(4) Change from standard synthetic resin (PVC) jacket material to an improved low temperature non-contaminating Polyvinyl Chloride material.
(5) Change in dimensional tolerances.
(6) Change in electrical properties from a nominal 73 ohm impedance to a 75 ohm nominal impedance.

If there were a precise and definitive understanding that all drop cables were to be either RG-59/U per JAN-C-17 or RG-59B/U per MIL-C-17, then there would be no question in regard to the physical construction of the cable, and the physical and electrical properties would be adequately outlined and understood. However, we do not have this precise and definitive understanding. As such, we can find as many variations in CATV drop cables being used as there are manufacturers.

To illustrate the need for standards, Ameco Cable undertook a field sampling of so-called RG-59/U cables, currently being used as CATV drop cables.

In Table D, we have reviewed the basic constructional details as found in some 19 different coaxial drop cables, listed or referred to as RG-59/U or Type RG-59/U cables. From this analysis, we find these variations in construction to exist:

(1) Conductors are either solid copper or copper-clad steel.
(2) Conductor sizes are 0.226", 0.0253" or 0.032".
(3) The insulating dielectric is either solid polyethylene or expanded (foamed) polyethylene.
(4) The outer conductor is generally composed of No. 34 AWG bare copper but there are cases where No. 36 AWG copper can be found. The number of copper ends per machine carrier varies along with the number of pics per inch. As such, the percent coverage of the outer conductor varies between 78% and 96.3%.
(5) The outer jacket material is either Polyvinyl Chloride (PVC) or Polyethylene.
(6) The overall cable diameters vary between 0.230" and 0.246".

TABLE B

INNER CONDUCTOR:	0.0253" PLAIN 'COPPERWELD'
INSULATION	SOLID TYPE A (POLYETHYLENE) DIAMETER: 0.146" ± .005"
OUTER CONDUCTOR.	SINGLE BRAID TYPE: BARE COPPER WIRE SIZE: 34 AWG CARRIERS: 16 ENDS: 7 PICKS/INCH: 8.2 ± 10%
JACKET:	TYPE I SYNTHETIC RESIN DIAMETER: 0.242" ± .008"
ENGINEERING DATA:	NOMINAL IMPEDANCE: 73 ± 3 ohms NOMINAL CAPACITANCE; 22.3 pf/ft. ATTENUATION: 55 mc — 2.4 db/100 ft. 83 mc — 3.0 db/100 ft 175 mc — 4.6 db/100 ft. 211 mc — 5.1 db/100 ft.

In this initial analysis, we have not tried to analyze the properties of the different grades of insulating and jacketing materials that have been used.

A detailed analysis of the various constructions reveals that material costs in the more expensive constructions can exceed the material costs in the least expensive constructions by as much as 46%. The commercial implications of this wide variation are self-evident.

We do not wish to infer that several or, for that matter, any of the constructions are unsuitable for the intended service. We have presented this review only to point-up the fact that the generic expression "RG" is a nebulous designation for a very important component of the CATV industry.

Standards to cover a CATV drop cable are relatively easy to develop, and it is probably that varying operating conditions would require more than a single standard construction. But, until such time as conditions are defined and specific constructions specified, the present conditions, which can best be described as chaotic, will prevail.

While variations in construction of aluminum sheathed cables for trunk and distribution service are not as prevalent as in the common drop cable, constructional differences do exist and, therefore, differences exist in the physical and electrical properties.

For example, from a review of various suppliers' printed data for .412" cable, we find that

TABLE C

INNER CONDUCTOR: 0.0230" COPPER COVERED STEEL

INSULATION: SOLID TYPE A (POLYETHYLENE)
DIAMETER: 0.146" ± .004"

OUTER CONDUCTOR: SINGLE BRAID
TYPE: BARE COPPER
WIRE SIZE: 34 AWG
CARRIERS: 16
ENDS: 7
PICKS / INCH: 8.2 ± 10%

JACKET: TYPE II a (NON-CONTAMINATING PVC)
DIAMETER: 0.242" ± .004"

ENGINEERING DATA:

NOMINAL IMPEDANCE: 75 ± 3 OHMS
NOMINAL CAPACITANCE: 21.1 pf/ft
ATTENUATION: 55 mc - 2.6 db/100 ft.
83 mc - 3.2 db/100 ft.
175 mc - 4.9 db/100 ft.
211 mc - 5.4 db/100 ft.

the nominal inner conductor diameter can vary between 0.075" and 0.081". These figures are shown in Table E.

In the area of polyethylene jacketed aluminum sheathed CATV cables, we again can find a wide variance in the constructional details. The indicated nominal polyethylene jacket walls and finished cable diameters as advertised by several manufacturers, are listed in Table F.

During the next few years, we will see an increasing demand for direct burial installations of aluminum sheathed CATV cables. Considerable concern has already been generated in the CATV industry over this subject and certainly the constructional variations as shown in Table F do not help the situation.

In regard to the subject matter of direct burial of cables, I would point out that in April 1964, the Institute of Electrical Engineers (IEEE) sponsored a 3 day technical conference on Underground Residential Distribution. This was followed in September 1966 by the 2nd Special Technical Conference on the same subject. Copies of the technical papers presented at these sessions are available thru IEEE.

Also, in the paper "Underground Installation of CATV Cables",[1] presented at the 14th Annual NCTA Convention, the author points out that the direct burial of aluminum-sheathed coaxial cables is not to

TABLE D

	Conductor		Insulation		Outer Conductor						Jacket		
	Mat.	Size	Mat.	O.D.	Mat.	Size	Ends	Picks	% Cov.	O.D.	Mat.	Wall	O.D.
RG-59/U	CS	.0253	P	.146	C	34	7	8.2	95.7	.191*	PVC	.035	.242
Brand A	CS	.0226	P	.146	C	34	7	8.0	95.6	.175	PVC	.035	.242
Brand B	CS	.0253	P	.146	C	34	5	8.0	81.3	.175	PVC	.030	.235
Brand C	CS	.0253	P	.146	C	34	7	8.0	95.6	.175	PVC	.035	.244
Brand D	CS	.0253	P	.146	C	34	5	10.1	84	.175	PVC	.030	.235
Brand E	CS	.0253	P	.146	C	36	6	8.0	78	.165	PVC	.035	.235
Brand F	CS	.0253	P	.146	C	34	7	8.0	95.6	.175	PVC	.035	.245
Brand G	CS	.0253	P	.146	C	34	7	6.0	94.0	.175	PVC	.035	.242
Brand H	CS	.0253	P	.146	C	34	5	10.8	84.0	.175	PVC	.032	.240
Brand I	CS	.0253	FP	.146	C	34	7	8.0	95.6	.175	PVC	.035	.245
Brand J	CS	.032	FP	.146	C	34	7	9.0	96.3	.175	PVC	.030	.240
Brand K	CS	.0253	P	.146	C	34	5	10.8	84.0	.175	PVC	.035	.242
Brand L	CS	.0253	FP	.150	C	34	5	10.8	84.0	.176	P	.030	.240
Brand M	CS	.0253	P	.146	C	34	7	8.0	95.6	.180	PVC	.035	.245
Brand N	CS	.0253	P	.146	C	34	5	12.0	88.0	.180	PVC	.035	.245
Brand O	C	.032	FP	.146	C	34	7	8.0	95.6	.185	P	.025	.230
Brand P	CS	.0253	P	.146	C	34	7	8.0	95.6	.180	PVC	.035	.246
Brand Q	CS	.0253	P	.146	C	34	7	8.0	95.6	.180	P	.035	.242
Brand R	CS	.032	FP	.146	C	34	7	8.0	95.6	.175	P	.035	.242
Brand S	CS	.0253	FP	.146	C	34**	7	8.0	95.6	.175	P	.035	.242

C - Copper
CS - Copper Covered Steel
P - Polyethylene
FP - Foam Polyethylene
PVC - Polyvinyl Chloride

* Max. O.D. Per Spec.
** Braid plus Copper backed Polyester Tape

be feared and can be economically and satisfactorily accomplished provided the cables are designed, manufactured and installed in accordance with established and proven standards and procedures.

Theoretical Considerations

Let us briefly review the general theoretical considerations for CATV cable design and also review briefly a few of the various process variables which can affect cable performance.

Table G outlines the components and general configuration of aluminum sheathed CATV coaxial cables.

d = diameter of the inner conductor
D = diameter over the conductor insulation
t = thickness of the aluminum sheath
O.D. = outside diameter of the cable

TABLE E

Cable Type: .412" Aluminum Sheathed CATV

Manufacturer	Inner Conductor Diameter (Nom.)
A	0.078"
B	0.077"
C	0.078"
D	0.0752"
E	0.075"
F	0.0752"
G	0.081"
H	0.075"
I	0.077"

The electrical design characteristics of such a coaxial cable are defined by the following interrelated equations:

(1) Characteristic Impedance (Z_o) =

$$\frac{138.2}{\sqrt{e}} \log_{10} \frac{D}{d} \text{ ohms}$$

Where e = Dielectric constant of the insulation

(2) Velocity of Propagation (Vp) = $\frac{100}{\sqrt{e}}$ percent

(3) Capacitance (C) = 1016 $\frac{\sqrt{e}}{Z_o}$ picofarads/ft.

Attenuation for these types of cables is defined by a more complex equation:

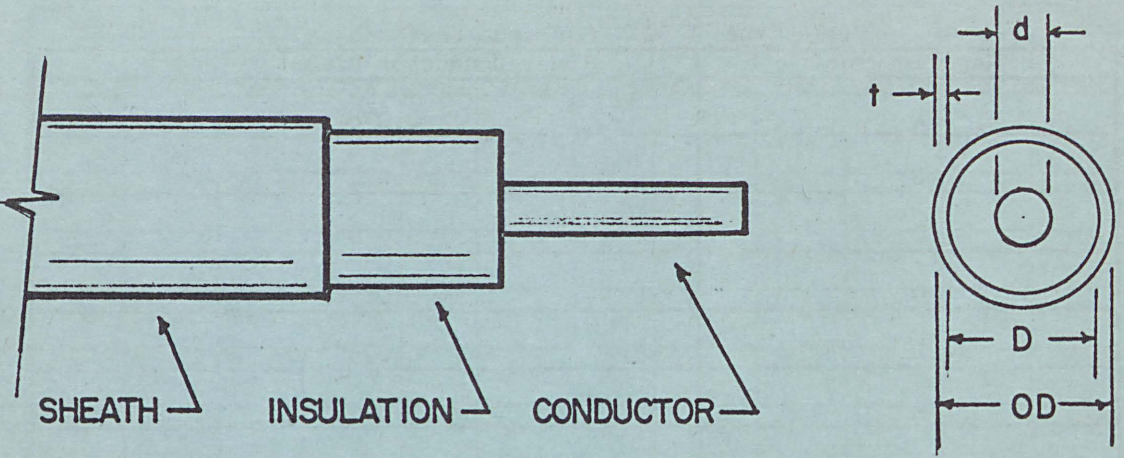
(4) $\alpha = 8.686 \left[\frac{R}{2Z_o} + \frac{GZ_o}{2} \right]$ db/1,000 feet

TABLE F

POLYETHYLENE JACKET WALL THICKNESSES

Manufacturer	.412"		.500"		.750"	
	Wall	O.D.	Wall	O.D.	Wall	O.D.
A	.029"	.470"	.040"	.580"	.037"	.820"
B	.035"	.482"	.040"	.580"	.050"	.845"
C	.034"	.480"	.038"	.575"	.050"	.850"
D	.050"	.512"	.050"	.600"	.050"	.850"
E	.050"	.512"	.050"	.600"	.050"	.850"
F	.034"	.480"	.040"	.580"	.050"	.850"
G	.025"	.480"	.025"	.580"	.036"	.850"
H	.040"	.495"	.050"	.605"	.050"	.855"
I	.029"	.470"	.038"	.575"	.038"	.825"

TABLE G



d — DIAMETER of INNER CONDUCTOR

D — DIAMETER OVER INSULATION

t — THICKNESS of SHEATH

O.D. — OUTSIDE DIAMETER of CABLE

Where R = effective loop resistance in ohms/ 1,000 ft.
Z_o = characteristic impedance in ohms.
G = leakage conductance of insulation in ohms/1,000 ft.

If the appropriate expressions for R, G and Z are substituted in this equation, we can write the expression for attenuation as:

$$\alpha = \frac{0.02387}{\text{Log}_{10}\ d_o/d_i}\left[\frac{\sqrt{P_i}\ \sqrt{e}\ \sqrt{f}}{d_i}\right] + \frac{0.02387}{\text{Log}_{10}\ d_o/d_i}\left[\frac{\sqrt{P_o}\ \sqrt{e}\ \sqrt{f}}{d_o}\right] + \frac{15.062\ fDe}{\text{Log}_{10}\ d_o/d_i}\ \text{db/1,000 ft.} \tag{5}$$

Where: α = attenuation in db/1,000 ft.
d_i = diameter of inner conductor (inches)
d_o = inside diameter of the outer conductor (inches)
P_o = resistivity of outer conductor (micro ohm - cm)
P_i = resistivity of inner conductor (micro ohm - cm)
e = dielectric constant of insulation (S.I.C.)
f = frequency in megacycles
D = dissipation factor of the insulation

In this expression, the first term represents the loss due to the inner conductor, the second term represents the loss due to the outer conductor and the third term represents the loss due to the insulation.

Process Variables

Basic specifications of the metal industry have established and defined resistivity values for copper and aluminum. For the purpose of this discussion, these values may be considered to be constant.

However, variations in the diameter of the inner conductor will occur during normal manufacturing operations. Wire drawing dies wear and cause diameters to increase. Also, normal handling procedures can cause "stretch" or "draw-down" of the conductor. The final electrical characteristics, particularly the cable impedance, can be quite sensitive to variations in the inner conductor diameter. Changes of 0.001" can change the impedance of .412" cable by as much as 0.6 ohms. In .500" cable such diameter variations can change the impedance by 0.5 ohms and .750" cable by 0.3 ohms. Therefore, the ability to hold close tolerances on the inner conductor dimensions, has an important bearing on the ability to maintain the cable impedance within given limits.

The diameter over the expanded polyethylene insulation is an important variable. When extruded correctly, the dielectric constant of expanded polyethylene is extremely constant. However, in the application of the aluminum sheath, the outer surface of the polyethylene tends to become compressed, thus effecting a change in the effective dielectric constant. The amount of compression is a matter of choice and will vary between manufacturers. In aluminum sheathed, foam polyethylene insulated CATV cables, the dielectric constant usually lies between 1.50 and 1.55. Variations in the dielectric constant of this extent can cause a difference of 1.0 ohm in impedance.

The thickness of the outer aluminum sheath is generally chosen to give the cable suitable mechanical properties. Variations in wall thickness and overall cable diameters can vary differently between manufacturers due to variations in the methods of application. Such variations must also be considered in establishing tolerance limits for both the mechanical and electrical characteristics.

Basically, a CATV cable will contain many minor structural changes in impedance along its length, each of which, by itself, is too minute to have any significant effect on the final electrical characteristics. If these structural changes occur with random spacing along the cable, they are of no special concern since they will tend to cancel out each other. If, however, these changes occur with a periodic spacing, they are of special concern. Under such conditions, there is one frequency at which the effect will be additive and the attenuation will be higher than it should be. Such a cable is said to have periodicity, and the spacing of these periodic irregularities determines the frequency at which their effect is additive.

Control of periodicity requires the meticulous study and analysis of every step of the manufacturing process where the cable or its components may be handled.

Initially, it was common practice to evaluate cable periodicity in terms of a sweep attenuation test. By this method, a sweep signal was introduced at one end of a length of cable and the signal emerging from the other end was displayed on an oscilloscope. Where periodicity occurred, a "hole" or "suck-out" would appear on the display at that frequency. By rough calibrations, the depth of the hole was determined in decibels. There were no established acceptance standards for this test although most spoke of 0.25 db or 0.50 db on the depth of the hole. Later, a percent deviation from the smooth curve theory was introduced. Limits of 2.5% and 5.0% were referenced, but again there were no established acceptance standards.

As cable manufacturing techniques improved, the magnitude of periodicity effects were reduced more and more until the depth of the holes became less than the resolution possible on the oscilloscope display. The best that could be said was -- "no measurable deviation from the smooth curve" -- certainly an imprecise statement to include in a specification.

During the past two years, manufacturers and users of CATV cables have become actively interested in "Return Loss" as a useful parameter for defining the quality of cable.

Return loss testing has been a valuable and highly sensitive test for evaluating electronic equipment for quite a few years. It is a rather sophisticated test, and the equipment and procedures used together with the results obtained required careful interpretation.

Return loss measurements are made by feeding a signal into one end of the cable and comparing the strength of this signal with the signal which is reflected back out of the same end. The ratio between the two, expressed in decibels, is said to be the return loss of the cable under test.

For CATV cables, the ideal condition would be zero reflection, since any signal which is reflected must reduce the strength of the transmitted signal, and it is the strength of the transmitted signal which effects the quality of the television picture carried to your subscriber's TV set. Thus, the higher the ratio between the main signal and the reflected signal, the better the cable.

The return loss test provides essentially the same information as the attenuation sweep test but with much greater sensitivity. It is this high degree of sensitivity that introduces problems in interpretation of the test method. The amplifiers used to achieve the needed sensitivity amplify not only the reflections coming from the cable but also those coming from connectors, terminations, jumpers, etc., and it is difficult to determine from the return loss measured just what part should be attributed to the cable and what part should be attributed to hardware.

When return loss measurements are made using the same equipment, hardware, and test procedures, and when the bridge adjustments and interpretation of results are always made to the same ground rules, this test can be a valuable asset for judging relative quality.

Since we do not have established standards and procedures for this test, it becomes difficult to make true comparative analyses between various cables on the market by simply reading the printed literature. For example, the following statements can be found in any of today's published literature:

(1) 26 db down min. Channels 2 through 13.
(2) 26 db down min. at any frequency 20-220 mcs.
(3) Minimum 26 db structural return loss across all Channels 2-13.
(4) 26 db min. in any TV channel measured by sweep method from 54 to 216 mcs (compared to average characteristic impedance).
(5) 25 db min. return loss at any frequency between 40 mcs to 230 mcs.
(6) Average USWR of 1.05 on all channels.
(7) Average minimum structural return loss at any frequency between 7 and 216 mcs in 32 db.
(8) Return loss - 26 db, 50-220 megahertz.
(9) 30 db return loss (weighted) worst point Channels (2-13).
(10) 25 db min. down at any frequency over the range 20-220 mcs, including sub channel frequencies 20-54 mcs, 88-105 mcs FM band, 105-174 mcs, as well as 12 VHF TV channels.
(11) 30 db loss on TV and FM bands.
(12) 30 db, 20-220 mcs as measured by the balanced bridge method.

Not having established written test procedures, and with such variations in indicated values, variations in test range, encompassed by such wordings as "minimum", "average", "average-minimum" and "weighted", it would be interesting to see how you, the user, would interpret these statements and evaluate each of the manufacturers.

This paper was introduced by stating that the objective was not to solve problems but rather to expose confusion, with the hope that such open discussion would lead to development and support of industry standards. I feel free, therefore, within the latitude of my expressed objective, to point out that vague "advertising copy" is hardly a satisfactory basis for sound engineering decisions.

The CATV system design engineer, on whose judgment millions of dollars are being committed is certainly entitled to more precise data than is commonly found in the advertising sections of trade magazines.

For example, average values without qualifying tolerances are misleading. It must be recognized that some variation is normal in any manufacturing process, and these variations are related directly to the principles of probability. Thus, with any normal processing, under control, as many values will be found above the average as will be found below the average. The actual range or spread of these values from the average will depend upon the degree of control capable of being effected over the process.

Nominal attenuation expressed graphically on fine paper with a broad pen is a poor basis for system design, and the expression "return loss" is just a catchy phrase unless the frequency spectrum and test procedures are precisely defined.

These are shoddy tools for an industry as sophisticated and advanced as CATV and certainly will not support improvement in the state of the art necessary for continued growth.

The wire and cable industry is capable of establishing concise and objective specifications to govern the design, production and testing of CATV cables now in general use. Past experiences in other industries proves that such standards can be devised and adopted without inhibiting progress. On the contrary, they have been the very basis for advanced designs. Such a project, however, can be undertaken only with the cooperation and mutual effort of both the manufacturer and the consumer. Ameco Cable, for one, stands ready to cooperate in establishing such standards which will give the manufacturer assurance that he is furnishing cable to meet the customer's requirements and give the customer confidence that he will receive what he has ordered.

In CATV, as in any area of technology, there must be mutual agreement and widespread use of test methods so that the language we use to describe, and the numbers we wish to measure, are universally understandable.

References:

1. "Underground Installation of CATV Cable," E. Mark Wolf, 14th Annual Convention, NCTA.

(Mr. Mills read his paper, marked No. 4.)
(Applause)

CHAIRMAN PENWELL: That was a very strong message. Archer Taylor told me this morning that yesterday at the NCTA Standards Committee meeting they did indeed appoint a panel of experts from the industry; and these people, during the coming year, will also be working on standards, for presumably cable specification and cable testing.

If anybody wants to stand up and say something, this is the time. We have completed our agenda. We thank you for attending.

(The meeting adjourned at 12:15 p.m.)